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Fungal loads of invertebrates in beech leaf litter

BY

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INTRODUCTION

It is generally agreed that soil and litter invertebrates have a profound effect on soil and litter fungi, especially through fragmentation of substrates and direct feeding (CROSSLEY, 1977 ; EDWARDS and HEATH, 1963 ; LUXTON, 1972 ; MITCHELL and PARKINSON, 1976). Additional studies have suggested that these invertebrates may also be important in the dispersal of soil and litter fungi (BUTCHER *et al.*, 1971; CARRÉ, 1964; CHRISTEN, 1975; DICKINSON, 1974; DOBBS and HINSON, 1960; FRANKLAND, 1966; GRAY and WILLIAMS, 1971; HARDING and STUTTARD, 1974; HEALEY, 1970; JACOT, 1930; MACFADYEN, 1963, 1964; MIGNOLET, 1971; POOLE, 1959; TALBOT, 1952; WINSTON, 1956; WITKAMP, 1960). Thus the study of the interactions between the soil and litter invertebrates and soil microfungi is an area worthy of investigation (GHILAROV, 1963; MACFADYEN, 1968; MIGNOLET, 1972).

This is the first in a series of papers reporting observations and experiments designed to discover the role of small invertebrates — especially mites and Collembola — in the dispersal of microfungi in the litter horizon of a beech forest. The litter horizon was selected because the invasion of fallen leaves by fungi capable of decomposing them is one of the first stages of nutrient recycling in forest ecosystems.

As a first step we report here our observations on those fungi which are associated with invertebrates. We emphasize the mites and Collembola since these groups are by far the most abundant in forest leaf litter and soil (BURGES and RAW, 1967; CHRISTIANSEN, 1964; DOEKSON and VAN DER DRIFT, 1963; GRAFF and SATCHELL, 1967; HALE, 1967; WALLWORK, 1970). Having presented the data we discuss the possible patterns of association between litter microfungi and the invertebrate fauna.

I. — MATERIALS AND METHODS

A. Site and substrata characteristics.

The site selected for study was Warren Woods in Berrien County in extreme southwest Michigan, U.S.A. These woods described by CAIN (1935) are reputed to be virgin and are presently protected as a state park. The beech trees *(Fagus grandifolia)* form almost pure stands at our study site although a few sugar maples *(Acer saccharum)* are established in the understory. There are few shrubs and the ground flora consists primarily of herbaceous perennials such as *Viola rostrata, Clintonia* sp., *Carex* sp., *Hepatica* sp., *Erythronium* sp. and *Sanguinaria canadensis.*

Qualitative and quantitative information on the litter microarthropods was obtained by a year-long series of simple Tullgren funnel extractions. At three to four week intervals three samples of litter 0.1 m^2 were collected intact from the study site, brought back to the lab and placed into a series of funnels separated into three litter horizons as follows:

L — the most recent year's leaf fall with leaves decomposing but still intact ;

F — leaf material which has been decomposing over a 2-3 year period with most leaves fragmented and discolored ;

H — amorphous material containing the most resistant compounds to decomposition (e.g. lignin) which is intermixed with the soil A horizon.

B. Extraction and culture methods.

To determine the fungi associated with the microarthropods, separate litter samples, with layering preserved intact, were brought to the lab and live animals were either 1) directly removed with sterile needles or forceps and transferred to culture plates or 2) simple funnel extractions were made with live individuals collected in a sterile container and then transferred aseptically. Each animal was placed in a separate culture dish, left for 24-48 hours, and then removed for identification. At first a variety of culture media were used, especially potato dextrose agar, Czapek-Dox agar, starch-casein agar and cellulose agar. However, these were eventually replaced by soil extract agar since it grew all the fungal species which had appeared on all the other media. In addition, soil extract was preferred due to slower growth rates and increased sporulation for all species isolated. After 72 hours at room temperature (25° C) and up to 120-168 hours with soil extract agar, isolations of the resultant fungal colonies were made onto malt extract and/or Czapek-Dox agar slant tubes for identification.

In some cases fungal growth had covered the animal prior to removal so that identification was restricted to the level of order. All pertinent information concerning the date, the litter layer located, the species identification as well as the fungal isolates obtained were recorded and correlated. A total of 459 litter organisms including 292 Acari, 49 Collembola and 45 Diplopoda were studied.

II. — RESULTS

A. Invertebrate population dynamics.

Figure 1 shows the results of the simple Tullgren funnel extractions for the period July 1976 to July 1977. Only the Acari, Collembola and Diplopoda are shown; the other groups of invertebrates including the Psocoptera, Pseu-

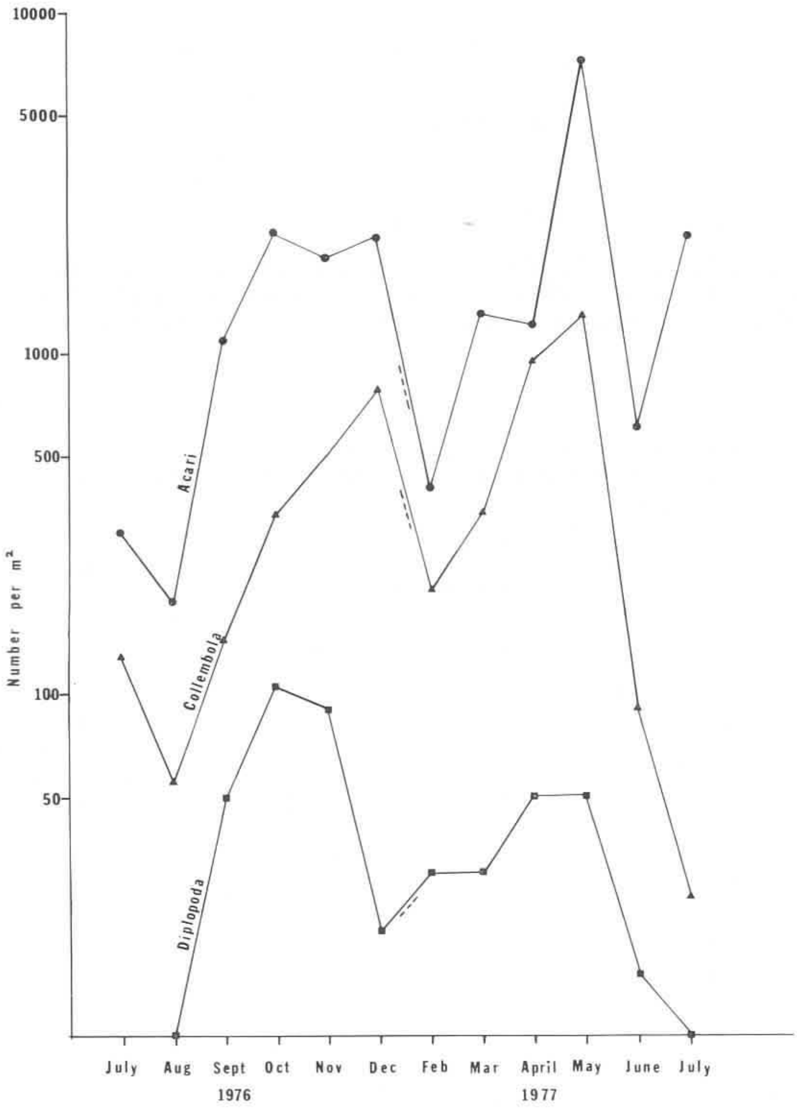

FIG. 1. — Number of individuals of Acari, Collembola and Diplopoda, per m² of beech leaf litter at Warren Woods, U.S.A. for the period July 1976 - July 1977. (semilogarithmic).

doscorpionida, Chilopoda, Isopoda, Coleoptera, Diptera, Araneida and Oligochaeta appeared with much lower frequency. The Acari and Collembola were found to be the two most abundant invertebrate orders. Acari average monthly densities in the leaf litter horizons were greatest at 2 300 and 7 300 individuals per m² for the fall and spring seasons while the Collembola numbered 770 and 1 300 individuals per m² at this time. These values are approximatly a factor of 10 below that of previous studies (WALLWORK, 1970;

HALE, 1967) but may be explained by firstly, the extraction method and secondly, by the sampling being restricted entirely to the leaf litter horizons exclusive of any soil horizons. Seasonal population fluctuations with peaks in autumn and spring coincided with the influx of immatures into the litter. The Diplopoda, an important order of leaf litter feeders, exhibited the same pattern.

B. **Microfungal loads of invertebrates.**

Table I presents the data on microfungi carried by a variety of litter organisms. The Acari collectively carried the greatest diversity (9 genera), followed by the Diplopoda and Oligochaeta (7), Collembola (6) and the Araneids (4). The remaining groups (totalling 37 individuals) were generally associated with only a single, *Penicillium.* This genus was the most common isolate, appearing on 76 % of the Collembola, 51 % of the Acari and 44 % of the Diplopoda. Its dominance was reflected in that 56 % of all invertebrates sampled carried it. *Cladosporium, Trichoderma* and *Martierella* were the next most frequent isolates although only 9 % of individuals carried them. Most individuals were associated with at least one fungal genus, the exception being the Acari with 20 % yielding no isolates.

TAB. I

Number and frequency (in parentheses) of fungal genera isolated from a variety of live litter organisms from Warren Woods, Michigan, U.S.A.

Order	N	*Penicillium*	*Cladosporium*	*Trichoderma*	*Mucor*	*Nortierella*	***Absidia*	N showing no fungal isolates
Acari	292	149 (.51)	31 (.10)	14 (.05)	5 (.02)	20 (.07)	13 (.04)	60 (.20)
Collembola	49	37 (.76)	4 (.08)	8 (.16)	3 (.06)	1 (.02)	2 (.04)	0
Psocoptera	6	3 (.50)	1 (.14)	—	—	—	3 (.50)	0
Pseudoscorpionida	4	4 (1.0)	1 (.25)	—	—	—	—	0
Diplopoda	45	20 (.44)	2 (.04)	5 (.11)	4 (.09)	6 (.13)	6 (.13)	6 (.13)
Chilopoda	4	4 (1.0)	—	—	—	—	—	0
Isopoda	5	5 (1.0)	—	—	—	—	—	0
Coleoptera (Staphylinidae, Carabidae)	14	11 (.78)	—	—	1 (.07)	3 (.21)	—	1 (.07)
Diptera larvae (Unidentified)	4	2 (.50)	1 (.25)	—	—	2 (.50)	—	0
Araneida (Linyphidae)	25	15 (.50)	10 (.33)	3 (.10)	2 (.07)	—	—	1 (04)
Oligochaeta	11	6 (.55)	2 (.18)	5 (.45)	1 (.09)	1 (.09)	2 (.18)	1 (.09)
TOTALS	459	256	52	35	16	33	26	69
FREQUENCY	—	.56	.11	.08	.03	.07	.06	

** Includes a few isolates of *Zygorrhynchus, Paecilomyces* and *Verticillium.*

Table II gives a more detailed breakdown of the microfungal loads from some of the animals reported in Table I. Mean number of fungal genera per individual ranged from 0.25 in the oribatid mites, *Phthicaracarus setosum* and *Hypochthonius rufulus*, to 2.21 in the Collembolan *Isotoma albella*. The loads of the majority of invertebrate carriers consisted of one genus only. A few of the larger animals such as coleopteran larvae, earthworms and millipedes carried up to four fungal genera.

TAB. II

Fungal genera diversity associated with beech leaf-litter invertebrates

Species	N	X no. fungal (genera) per animal	Percentage of animals carrying the following number of fungal genera				
			0	1	2	3	4
Acari :							
Galumma ithacensis	76	.46 ± .74	67	21	10	1	—
Phthicaracarus setosum	51	.25 ± .48	76	21	1	—	—
Hypochthonius rufulus	8	.25 ± .46	75	25	—	—	—
Scheloribates sp.	17	.53 ± .80	65	18	18	—	—
Unidentified (Oribatid)	38	1.10 ± .34	—	87	12	—	—
Veigaia nemorensis	9	.67 ± .50	33	67	—	—	—
Collembola :							
Entomobryoides purpurascens	4	1.25 ± .96	25	25	50	—	—
Isotoma albella	14	2.21 ±1.37	14	14	29	36	7
Frisea clavisela	14	.50 ± .65	57	36	7	—	—
Ptenothrix marmorata	6	1.17 ± .55	0	83	17	—	—
Diplopoda :							
Unidentified sp.	31	1.29 ±1.07	19	48	23	6	3
Araneida :							
Linyphiidae	10	1.30 ± .82	10	60	20	10	—
Oligochaeta :							
Lumbricidae	9	2.0 ±1.41	11	33	22	11	22
Coleoptera :							
Staphylinidae	7	1.43 ± .98	14	43	29	14	—

The loads of a subset of the total Acari, Collembola, and Diplopoda are analyzed in terms of the constituent fungal species in Table III. The order of importance indicated in Table I is reinforced here with twelve species of *Penicillium* dominating the loads followed by single species of *Cladosporium*, *Trichoderma*, and *Mortierella*. There was little indication of specificity between any invertebrate species and the fungal species which were transported. For the unidentified categories (those individuals covered by fungi prior to their removal from agar culture) however, *Penicillium* was the dominant isolate.

TAB. III

Fungal loads of selected invertebrate individuals from beech litter

	Fungus species N	*Penicillium* lanosum	commune	thomii	raistrickii	frequentans	unidentified sp. # 22	# 23	# 25	# 39	# 109	# 112	*Cladosporium* cladosporiodes	*Trichoderma* koningii	*Mucor* sp.	*Mortierella* sp.	*Absidia* sp.	*Zygorrhynchus* sp.	*Paecilomyces* sp.	*Verticillium* sp.
Invertebrate species																				
Acari:																				
Galumna ithacensis............	76	5	3	—	1	2	—	1	—	—	—	—	11	2	—	—	—	—	—	1
Phthicaracarus setosum.........	52	—	—	—	—	—	—	—	—	1	—	—	3	1	—	3	—	—	—	—
Scheloribates sp..............	17	2	1	—	—	—	—	—	—	—	—	—	3	3	—	2	—	—	—	—
Epidamaeus sp................	9	5	—	—	—	—	—	—	—	—	—	—	1	3	—	—	—	—	—	—
Unidentified (Oribatid)........	45	11	12	3	2	5	—	2	1	2	—	—	5	4	—	8	1	—	—	—
Unidentified (all orders).......	85	57	4	5	—	3	8	2	1	1	6	2	7	1	5	6	1	2	4	3
Collembola:																				
Entomobryoides purpurascens....	4	1	—	—	—	1	—	—	—	—	—	—	—	1	—	1	—	—	—	—
Isotoma albella................	14	—	—	—	—	2	—	—	—	—	—	—	3	5	1	—	—	—	—	1
Ptenothrix marmorata..........	8	6	—	—	—	1	—	—	—	—	—	—	—	—	1	—	—	—	—	—
Unidentified (all orders).......	25	13	—	5	1	1	2	3	—	—	—	1	1	—	1	—	—	—	—	1
Diplopoda:																				
Unidentified sp................	45	10	3	1	—	—	—	—	4	—	1	1	2	5	4	6	3	3	—	—

III. — DISCUSSION

It is apparent from the preceding results that leaf litter invertebrates do carry microfungi. While various authors (Christen, 1975; Ghilarov, 1963; Macfadyen, 1968; Mignolet, 1972) have suggested this interaction, this is the first study to quantify it.

A wide diversity of invertebrate orders transported the same fungal genera although in varying proportions. The Acari averaged 0.5 genera per individual although 20 % of the individuals were found to be carrying no viable fungal material. The species of Collembola were more variable with respect to the number of genera carried, ranging from 0.5 to over 2.0 per individual. Other orders such as Coleoptera, Araneida and Oligochaeta, represented by individuals of a much larger size, averaged 1 to 2 genera per individual. This was probably due to their greater body surface area. The number of fungal genera isolated from animals was highest during the spring and autumn seasons, coinciding with the invertebrate population peaks (Fig. 1).

The most frequently isolated genera were *Penicillium*, *Cladosporium*, *Trichoderma*, and *Mortierella*. All of these are known to be in the scheme of fungus succession on deciduous leaf litter (Hudson, 1968, 1971; Jensen, 1974). The studies of Hogg and Hudson (1966), Jensen (1963), and Saito (1956) show that these fungal genera are among the most frequent isolates obtained from *Fagus* leaf litter (Tb. IV). Since these studies were carried out in different areas of the world the similarity in the litter fungi is remarkable.

Tab. IV

Common fungal genera isolated from beech leaf litter studies

	Saito[1]	Jensen[2]	Hogg & Hudson[3]	Pherson[4]	Ruscoe[5]
Absidia	×	×		×	
Mucor	×	×		×	
Phoma	×			×	×
Trichoderma	×	×	×	×	×
Penicillium	×	×	×	×	×
Verticillium	×	×		×	
Cladosporium	×	×	×	×	×
Alternaria	×		×	×	×
Fusarium	×	×		×	×
Mortierella		×	×	×	
Botrytis		×	×		×
Aureobasidium			×		×
Epicoccum			×	×	×

1. *Fagus crenata.*
2. *Fagus sylvatica.*
3. *Fagus sylvatica.*
4. *Fagus grandifolia.*
5. *Nothofagus truncata.*

It may be questioned why these fungi, among all those involved in the leaf litter decomposition process, were associated with the leaf litter invertebrates. Several possibilities exist including fungal attributes such as 1) numerical abundance 2) high inoculum potential e.g. heavy sporulators 3) specialized dispersal mechanisms and/or morphological features which are adaptive to dispersal by litter invertebrates and 4) attractiveness as food sources for litter invertebrates.

Numerical abundance is a possibility suggested through soil dilution plate isolations (JENSEN, 1963). However, this is more likely to be a reflection of the degree of sporulation within the genera, e.g. *Penicillium*, *Cladosporium*, and *Mortierella* are considered to be heavy sporulators. In addition, enhanced dispersal ability may result from specialized conidial (or spore) morphologies which result in their becoming attached to invertebrates. However, no consistent pattern can be seen since the easily dislodged « dry-spored » *Penicillium* and *Cladosporium* morphologies, the « wet-spored » *Trichoderma*, and the sporangia of *Mortierella*, probably represent highly disparate dispersal methods.

It has been demonstrated (although conflicting results exist between laboratory and field data (MITCHELL and PARKINSON, 1976) that fungal food preferences occur within various soil/litter animals (ANDERSON, 1975; ANDERSON and HEALEY, 1972; FARAHAT, 1966; HARTENSTEIN, 1962; LUXTON, 1972). Generally the most preferred genera were *Cladosporium*, *Trichoderma*, *Phoma*, and *Aureobasidium* while the least preferred genera were *Penicillium* and *Aspergillus*. While feeding provides support to the presence of *Cladosporium* and *Trichoderma* isolates, it fails to explain the dominance of *Penicillium* isolates.

Invertebrate dispersal of fungi may occur in two ways. First, a situation analogous to pollination systems may occur whereby the animal, while feeding on a fungal colony, becomes covered with additional spores which are then carried about. Secondly, spores or viable hyphae may pass through the gut and be dispersed via feces (CHRISTEN, 1975; MIGNOLET, 1971; POOLE, 1959; WITKAMP, 1960).

While all of these commonly isolated genera are known to have the ability to decompose leaf litter (BOOIS, 1976), it was of special interest to discover that *Penicillium*, *Trichoderma*, and *Mortierella* have the additional capacity to decompose chitin (HUDSON, 1972). This prompts the speculation that invertebrates carry a flora which will decompose the body cuticle shortly after death. This is supported by the fact that those invertebrates that died while on agar culture plates yielded *Penicillium* and to a lesser extent *Mortierella* colonies from their bodies.

It has been shown that leaf litter invertebrate-microfungi associations do occur. The importance of the role of invertebrates in the dispersal of fungi is still questionable although additional studies are being done to resolve this. Fungal community structure and composition as well as the subsequent decomposition process may well depend on this interaction (MITCHELL and PARKINSON, 1976). The activities of leaf litter invertebrates which reach a maximum abundance during the fall and spring at the same time as bursts of microfungal growth (BOOIS and JANSEN, 1976; NAGEL-deBOOIS and JANSEN, 1971) may be critical to the inoculation and fragmentation of leaf material.

Although the role of water may provide an alternative method for fungus dispersal, results are conflicting (BANDONI and KOSKE, 1974; HEPPLE, 1960). Nevertheless the role of biological agents in the regulation of decomposition processes and subsequent nutrient cycling is an exciting but difficult field of investigation worthy of future studies.

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SUMMARY

Twenty species of fungi from nine genera were isolated from living beech leaf litter-inhabiting invertebrates. *Penicillium, Cladosporium, Trichoderma,* and *Mortierella* genera were the most frequent isolates. Possible patterns of association between litter microfungi and the invertebrate fauna are discussed.

RÉSUMÉ

Vingt espèces de champignons appartenant à neuf genres ont été isolées à partir d'Invertébrés vivant de feuilles de hêtres décomposées. Les genres les plus fréquemment isolés ont été *Penicillium, Cladosporium, Trichoderma* et *Mortierella.* Quelques modèles possibles d'association entre les microchampignons de décomposition et la faune d'Invertébrés sont discutés.

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